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REPORT No. 154

A STUDY OF TAKING OFF AND LANDING AN AIRPLANE

By T. CARROLL

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A STUDY OF TAKING OFF AND LANDING AN AIRPLANE

By T. CARROLL
Langley Memorial Aeronautical Laboratory

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length	l	meter	m.	foot (or mile)	ft. (or mi.).
Time	t	second	sec.	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg.	weight of one pound	lb.
Power	P	kg.m/sec		horsepower	HP
Speed		m/sec	m. p. s.	mi/hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W = mg$.

Standard acceleration of gravity, $g = 9.806 \text{m/sec.}^2 = 32.172 \text{ ft/sec.}^2$

Mass, $m = \frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6° C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, $1.223 \text{ kg/m.}^3 = 0.07635 \text{ lb/ft.}^3$

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k, by proper subscript).

Area, S; wing area, S_w, etc.

Span, b; chord length, c.

Aspect ratio $= b/c$

Length of body (from c. g. to elevator hinge), f.

Coefficient of viscosity, μ

3. AERODYNAMICAL SYMBOLS.

True air speed, V

Impact pressure, $q = \frac{1}{2} \rho V^2$

Lift, L; absolute coefficient $C_L = \frac{L}{qS}$

Drag, D; absolute coefficient $C_D = \frac{D}{qS}$

Cross wind force, C; absolute coefficient $C_C = \frac{C}{qS}$.

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

Angle of setting of wings (relative to thrust line), i_w

Angle of setting of horizontal tail surface, i_t

Reynolds Number $= \rho \frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model aerofoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of c. p. from leading edge to chord length), C_p.

Angle of tail setting, $(i_t - i_w) = \beta$

Angle of attack, α

Angle of downwash, ϵ

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A STUDY OF TAKING OFF AND LANDING AN AIRPLANE.

By T. Carroll.

SUMMARY.

This report covers the results of an investigation carried on at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics for the purpose of discussing the various methods of effecting the take-off and the landing of an airplane, and to make a direct analysis of the control movements, the accelerations, and air speeds during these maneuvers. The recording instruments developed at the laboratory were used in this test and the records obtained by them were made the basis for a comparative study of the two extreme methods of taking off (the tail-high and the tail-low methods) and of various types of landings. It is believed that this is the first time that an accurate record has been obtained of the movements of the controls during these important maneuvers, and the records are of further interest from the fact that they were taken synchronously with records of the air speed and acceleration.

The records themselves should be of considerable value to a student pilot in enabling him to visualize the movements of the controls and the consequent effect upon the air speed and acceleration. This opens a very important field for research in the study of the technique of piloting, either of student pilots or for the "refresher" courses or other checking up of pilots in general. With these instruments it will be possible to obtain records of the maneuvering of any pilot in practically any type of airplane, and from the records so obtained any fault or roughness can be immediately noted. This can be done not only in the maneuvers of taking off or landing but in any sort of straight flight or "stunting."

INTRODUCTION.

The whole of the art of flying may be divided into three very distinct phases, each entirely different from either of the remaining two—namely, taking off, flight proper, and landing. Of the second phase, comprising, as it does, flying itself, this article is not concerned; it is the first and third that are to be considered.

Taking off and landing, the beginning and the end of a flight, while truly not flight at all, are the pivotal parts in the education of a student pilot and are the determining factors in the proficiency, even perhaps in the longevity, of the lachèd pilot. Of the two, landing is perhaps the more important, for it is to this phase of flying that the major amount of accident and damage have accrued. Hence, even to the pilot of very long standing the study of the intricacies of taking off and landing and the methods of perfection therein is not inept.

But very little attention has been accorded these very important maneuvers by technical writers, and with a single exception no information of a thorough and serious nature is available. This exception is the paper of Squadron Leader R. M. Hill, M. C., A. F. C., "The Maneuvers of Getting Off and Landing." This paper, originally read before the Royal Aeronautical Society of Great Britain by the author, has appeared serially in the American technical press (Aerial Age). Major Hill has treated the subject with exceptional thoroughness and detail, and his discussion is particularly of interest, as he is one of the finest service pilots in England and has a brilliant war record. The present work was undertaken at N. A. C. A. laboratory as an extension of Major Hill's text, and particularly to place the data obtained by recording instruments beside it.

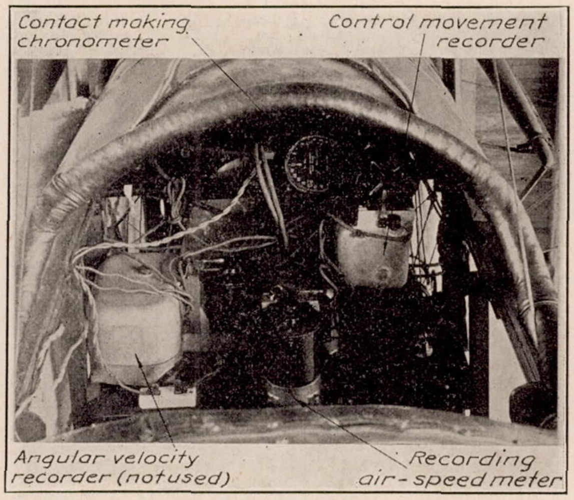
Taking off, while not generally thought of as requiring the amount of skill of a landing, is in many respects not unlike that maneuver. Both are translational periods passing through

the stalled flight condition. Thus the hazard in either of the maneuvers is almost invariably due to improper tempo in the placing of the stalled period. A stall, it will be understood, is that period in the flight of an airplane when through any of several causes the air speed of the airplane in the direction of the longitudinal axis is below the speed which will enable the wings to bear it in level flight. However, from a purely technical viewpoint, the absolute stalling point would be more correctly considered to be slightly beyond this—that is, at the point where the airplane passes from the control of the pilot due to this loss of speed.

As it will also be recognized, there are two agencies which will tend to maintain an airplane in stable flight—firstly, the power transmitted through its engine and propeller, and, secondly, by taking advantage of the forces of gravitation. It will be likewise seen that there are a number of causes which can effect a stall: A sudden diminution of engine power when the air speed is near the stalling point; a sudden increase in the angle of attack under like conditions; or any turning of the flight path (excepting, of course, in the direction of the forces of gravitation) when at a large angle of attack. In short, any change of the flight path which overtaxes the agencies providing the support and control of the airplane will cause them to cease to function as such. Hence, it is of paramount importance to remember that in the maneuver of taking off or of landing all of the eventualities of stalled flight must be at least contemplated, whether actually encountered or not. That different types of airplanes behave differently under stalled conditions while true will not be considered here; but that nearly all airplanes when stalled will lose their stable flying qualities and their controllability is axiomatic.

INSTRUMENTS AND INSTALLATION.

At the Langley Field laboratory of the National Advisory Committee for Aeronautics records have been taken with the recording instruments developed there which bring out very distinctly the rapidly changing conditions of speed, load, etc., and the movements of control surfaces which produce these phenomena. These instruments were the recording air speed meter,[1] the accelerometer,[2] and the control position recorder.[3]



Instrument installation.

The illustration of the installation of the instruments in the airplane used, a Curtiss JN4h, Wright Model E 180 H.P. motor, is neither exact nor complete, as one instrument shown in the illustration was not used, while one other instrument, very similar in its external characteristics, was used, but was so placed on the floor of the forward cockpit as to be difficult to photograph. It serves, however, to illustrate the appearance of the instruments used and the installation thereof.

The illustration of the actual records obtained show the film as taken from the instrument from which the replotting is made. The retracings of these records, herein reproduced, are corrected from the calibration of the instruments and the precision is ± 2 m. p. h. in the air speed, ± 0.2 g. in the acceleration, and $\pm 1°$ in the control angles. All the records were carefully synchronized by an electric chronometer, which marked all the records simultaneously every 3 seconds.

TAKE-OFF.

There are two methods in which a take-off may be consummated—namely, by the so-called tail-high method and the tail-low method. A tendency toward one or the other of these extremes is often advocated, and it is of course true that for differently proportioned airplanes quite different procedure in the manner of taking off is necessary. To those pilots who have

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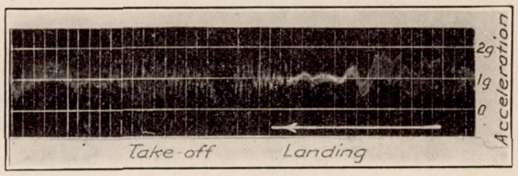
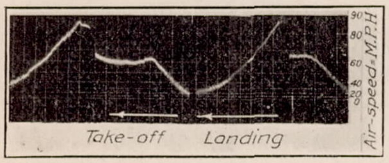
[1] N. A. C. A. Technical Note No. 64. [2] N. A. C. A. Report Nos. 99 and 100. [3] N. A. C. A. Technical Note No. 97.

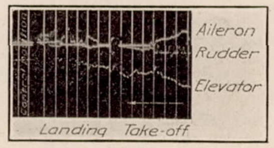
given the matter more than casual attention it will be patent that the ideal for varying conditions is a varying ideal, and is somewhere between the two extreme methods.

Conditions as to terrain, wind, etc., being normally good—that is, from an airdrome, as distinguished from an emergency take-off from a small, poorly surfaced field—a consideration of the tail-high method can be taken to begin with the airplane headed upwind, with good surface and sufficient unobstructed runway and climbing space directly ahead, and the motor running well.



Thus with the flight ready to begin the engine is opened slowly to its best revolutions per minute, and as the airplane begins to move along the ground the tail is raised by pushing the stick forward, lowering the elevators. The airplane rolls along the ground in an attitude approximating the flying position—i. e., with the top longeron nearly parallel to the ground. Then gradually as the speed increases it may be found that the tail tends to rise too high, in which case a lessening of the pressure forward on the stick, permitting that control to approach the neutral position, will alleviate the condition. At the same time yawing, due to directional instability and torque, is often encountered, necessitating considerable rudder action to maintain the desired direction. Neglecting for the moment any unusual movements brought about by outside influences, as gusty wind or rough ground, the wings, as the speed increases, are gradually picking up a load, culminating at the point in the speed range where the wings are exactly able to bear the total weight of the airplane and its load at that angle of attack. At this point the wheels are still touching the ground but supporting no weight, as it is now borne by the wings. However, at this point the airplane does not leave the ground of itself, but at the next moment, as the speed continues to increase, the lift developed by the wings exceeds the total weight and the airplane, unassisted by the pilot, lifts *itself* into the air. It will then continue to collect speed, and as the best climbing speed is attained the pilot may then essay whatever maneuvers he may desire with the assurance that his airplane is well within the limit of safety in regard to stalling.





In the other manner of taking off, with the tail well down, the airplane is started rolling along the ground as before, but as soon as the tail starts to rise it is arrested, and, on the theory that the machine rests upon the ground at the angle which gives to its wings the highest lift, the tail is held only a very small space from the ground, and by means of the elevator the airplane is literally lifted from the ground at the earliest moment.

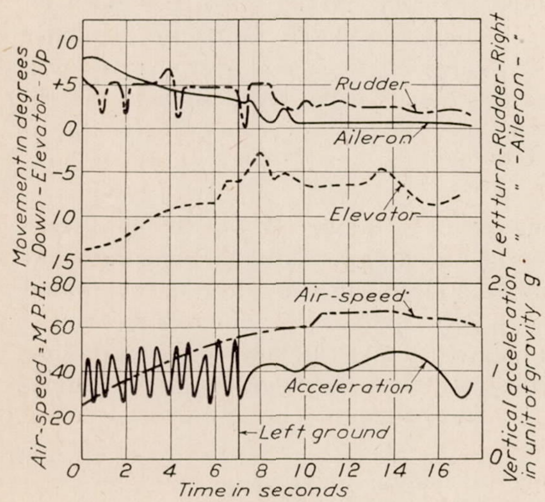


FIG. 1.—Tail-high "take-off."

In figure 1 a composite record of the readings from the instruments mentioned above is given, representing the control positions, the air speed, and the vertical acceleration (or loading) on an airplane during a tail-high take off. It will be observed that the beginning of the record shows the speed as 22 m. p. h., which, as the velocity of the wind at that moment was in the vicinity of 16 m. p. h., represents a ground speed of about 6 m. p. h., the recording instruments being switched on soon after the machine started to move over the ground. It is also observed that the elevator was depressed to 14°, very near its maximum, that it was let up only a few degrees until the point at which the airplane left the ground, and that at no time during the record the elevator was in or above the neutral position. The

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air-speed curve is very regular up to 60 m. p. h., the airplane leaving the ground at 55 m. p. h. in 6½ seconds after the beginning of the record.

In figure 2 with the same machine and equipment and under the same conditions a tail-low take-off was made. The airplane left the ground in 6 seconds at 40 m. p. h. It will be noted that the elevator was in relatively the same postition at the start but that the stick was pulled back very early and that at the point that the take-off was effected the elevators were above neutral and continued so till the plane was well clear of the ground.

By a comparison of the two figures several marked differences are found. In the air-speed curve the tail-high record is very smooth and quickly reaches a safe speed (60 m. p. h.) in 10 seconds. In the tail-low record the speed curve is flatter and very irregular, each depression in the curve representing a tendency to lose speed—hence, stall—and that the speed of 60 m. p. h. was not attained until 17 seconds. In the rudder and aileron controls the action during the tail-high take-off was much smoother while moving along the ground, and much smoother in the air, indicating that in the tail-low take-off it was necessary to fight for good control against the tendency to stall mentioned in connection with the air-speed curve. The vertical acceleration is smoother and of considerably less magnitude in the tail-high record, and when it is considered that this represents, up to the take-off point, the shock which must be absorbed by the landing chassis and shock absorbers, it is of importance to keep the acceleration low and smooth.

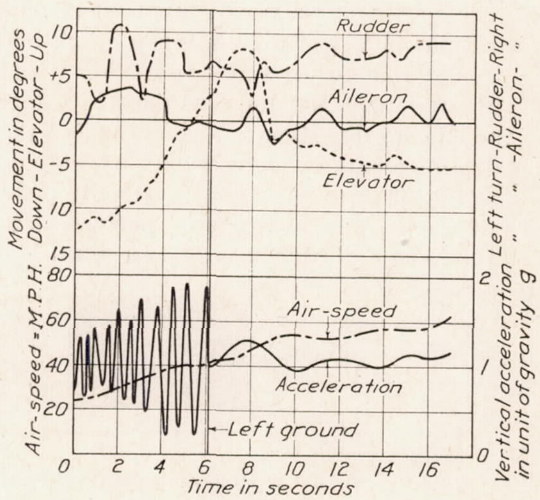


FIG. 2.—Tail-low "take-off."

The conclusion therefore must be reached that the tail-high take-off is the better wherever it is possible to use it. However, there are, of course, conditions, as of very bumpy ground, when it may be more advantageous to use the other method and permit the airplane to be bumped into the air and to stagger off in that manner, hoping to get the nose down and pick up speed just above the ground in the manner of a tail-high take-off. At any rate, it is believed that the manner of take-off should approach the high-tail manner as closely as practicable under all conditions, even in the forced maneuver of taking off from small fields and over obstructions, with the alternative of zooming the obstructions rather than crossing them in more nearly regular flight but in the vicinity of questionable control.

LANDING.

In landing the same conditions are to be encountered as in taking off, but in the reverse order. As in the take-off, we have again the question of passing gracefully through the point of stalling. As a matter of fact, a landing is essentially a stall executed as close to the ground as possible. Unfortunately, for this discussion, the purely mechanical movements of the control system as recorded by the instruments above mentioned and the consequent variations in speed and loading also recorded are of minor import compared to the judgment and coordination of the pilot in regard to the manner of approach, selection of landing ground with regard to the direction of the wind, and the terrain.

While in practice there is but one accepted manner of landing an airplane—i. e., on three points (the wheel landing being no longer considered good practice)—there is at least a theoretical possibility of making a three-point landing in two ways: First, from a fast glide, by leveling off as close to the ground as is possible and permitting the airplane to lose its speed gradually while held in relatively horizontal flight. In so doing it will be found that a gradual easing back of the stick has unconsciously occurred, so that at the moment the flight speed has diminished to the stalling point the stick is pulled back to its farthest point and hence the tail is well down.

And in the second manner, to glide in at a speed as close as possible to the stalling point and when at the desired height from the ground quickly to pull back the stick, so pulling the tail down very quickly and thus attaining the desired stall with a certain suddenness.

Disregarding entirely the matter of approach, either of the two means of effecting a landing would be well enough, providing that such proficiency in executing the second method is acquired, that the average quality of the landings so made would be reasonably high. But it is

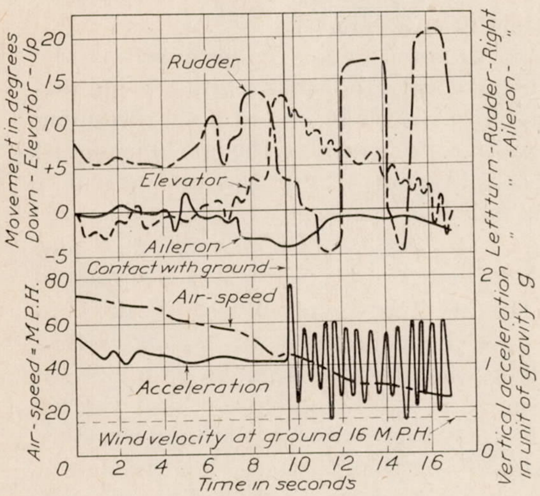


FIG. 3.—Three-point landing.

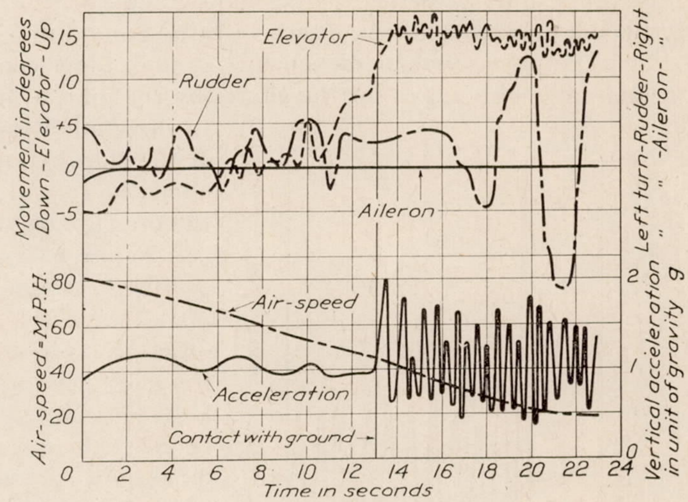


FIG. 4.—Three-point landing.

quite evident that the nicety of judgment required for the habitual use of such a method would only be reached after a very considerable amount of practice, and in taking this practice serious difficulties may be encountered, particularly in passing through the eddies and unevenness of the air around hangars and other obstructions at the edge of the airdrome. In general, therefore, it would seem to be better to use the first method entirely for landing in an airdrome, leaving the other method for use solely in the exigency of a forced landing on poorer ground.

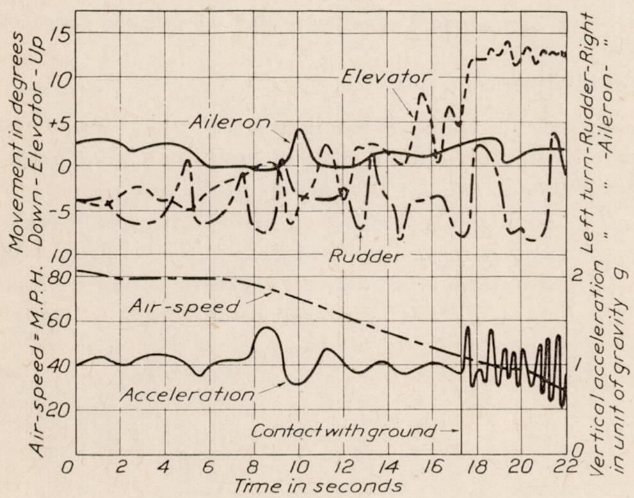


FIG. 5.—Three-point landing.

The figures 3, 4, and 5 are reproductions of curves taken from records from the same instruments and in the same manner as those regarding take-offs, and represent three landings, each a fairly good three-point landing on relatively good ground. It is particularly interesting to note the smooth deceleration in the air-speed curve and the fact that in each case the first contact with the ground was made at exactly 44 m. p. h. This represents quite conclusively that this is the normal stalling speed, hence landing speed, of the airplane, the landings being made at minimum throttle and entirely by the first method above outlined. Examination of the curve of the elevator control angle clearly indicates that the stick was very gradually pulled back beginning in an ordinarily fast glide, and just before leveling out, at a speed of about 80 m. p. h. in each case. Furthermore, it will be noted that this gradual pulling back brought the stick well back at the instant the airplane came in contact with the ground. Irregularity in these elevator curves can be attributed to two causes. The smaller irregularities of figures 3 and 4 are more probably due to

backlash in the control cables, while the larger ones in figure 5 are due to overcontrol. This is borne out by an examination of the acceleration curve during the interval just before the landing point, the larger fluctuation in figure 5 in combination with the very irregular elevator curve showing that it was necessary to redress on five distinct occasions.

It is interesting to note in this respect the influence of pure good fortune in making a landing, for while the curves in figures 3 and 4 represent much cleaner piloting technique than in figure 5, nevertheless the acceleration curve after the landing point shows that the machine made a much smoother contact with the ground in 5 than in either 3 or 4.

The rather violent movements in the rudder control as noted in the rudder curves of the landing records represent the efforts by the pilot to frustrate any tendency to ground spin due to directional instability. Also in record 3 the dropping of the elevator curve back to neutral as the machine moved along the ground is the lessening of the stick pull to relieve the pressure on the tail skid.

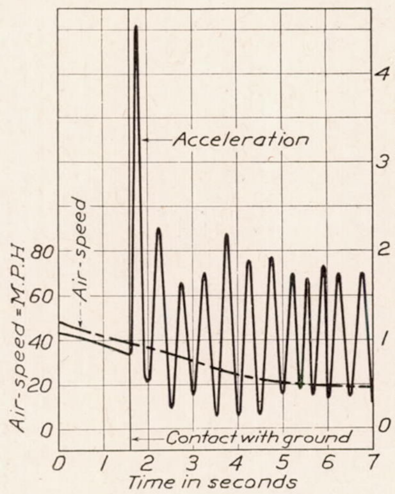
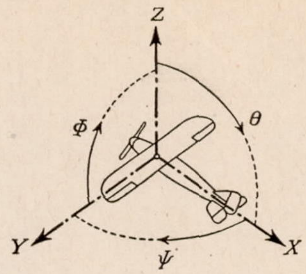


FIG. 6.—Six foot pan-cake landing. Brake shock absorber.

Figure 6 is an interesting record of the air speed and acceleration in a very bad landing. This was a purposely made "pancake" landing from about 6 feet—that is, to observers stationed on the airdrome it was estimated that the airplane was about that distance from the ground when "the bottom fell out." It will be noted also that the air speed at the instant the wheels struck the ground was only 38 m. p. h., or 6 miles slower than any other landing shown. The student pilot is usually rather awestricken when an instructor mentions that the leveling out must be done within a foot or two of the ground. Perhaps this example of the consequences of leveling off at the not particularly exorbitant altitude of 6 feet will serve to clarify the necessity for the instructor's remark. Assuming that the airplane, loaded, weighs in the neighborhood of 1 ton, it is evident, as the acceleration curve exceeds 4.5 g., that the landing gear had to take an overload of approximately $3\frac{1}{2}$ tons. So it is small wonder that shock-absorber elastics break, as they did in this case.

CONCLUSIONS.

The results obtained in this investigation are of value in analyzing the behavior of the airplane in landing and taking off, as well as recording the pilot's style of handling the airplane. It is recommended that more work of this kind be carried out by various pilots and on several types of airplane in order to obtain information as to the properties of a machine which make it easy to land, and the style used by the pilots who make the best landings. It would be desirable in further work to add to the three sets of records obtained here records of the inclination of the machine with a kymograph and the height above the ground by means of a trailing arm.



Positive directions of axes and angles (forces and moments) as shown by arrows.

Axis.		Force (parallel to axis) symbol.	Moment about axis.			Angle.		Velocities.	
Designation.	Symbol.		Designation.	Symbol.	Positive direction.	Designation.	Symbol.	Linear (component along axis).	Angular.
Longitudinal....	X	X	rolling.....	L	$Y \longrightarrow Z$	roll......	Φ	u	p
Lateral..........	Y	Y	pitching...	M	$Z \longrightarrow X$	pitch....	θ	v	q
Normal..........	Z	Z	yawing.....	N	$X \longrightarrow Y$	yaw.....	Ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{q\,b\,S},\ C_m = \frac{M}{q\,c\,S},\ C_n = \frac{N}{q\,f\,S}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS.

Diameter, D
Pitch (a) Aerodynamic pitch, p_a
(b) Effective pitch, p_e
(c) Geometric pitch, p_g
Pitch ratio, p/D
Inflow velocity, V′
Slip-stream velocity, V_s
Thrust, T

Torque, Q
Power, P
(If "coefficients" are introduced all units used must be consistent.)
Efficiency $\eta = T\,V/P$
Revolutions per sec., n; per min., N.
Effective helix angle $\Phi = \frac{V}{\pi\,D\,n}$

5. NUMERICAL RELATIONS.

1 HP = 76 kg. m/sec. = 550 lb. ft/sec.
1 kg. m/sec. = 0.01315 HP
1 mi/hr. = 0.4470 m/sec.
1 m/sec. = 2.237 mi/hr.

1 lb. = 0.4536 kg.
1 kg. = 2.204 lb.
1 mi. = 1609 m. = 5280 ft.
1 m. = 3.281 ft.

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